PROCEEDINGS OF SCIENCE

Nucleosynthetic post-processing of Type Ia supernovae with variable tracer masses

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The post-processing of passively advected Lagrangian tracer particles [1] is still the most common way for obtaining detailed nucleosynthetic yield predictions of Type Ia supernova (SN Ia) hydrodynamical simulations. Historically, tracer particles of constant mass are employed. However, intermediate mass elements, such as e.g. Ne, Mg, Al, or Si, are typically synthesized in the outer layers of SNe Ia, where due to the lower initial density a constant mass tracer distribution results in poor resolution of the spatial morphology of the abundance distribution. We show how to alleviate this problem with a suitably chosen distribution of variable tracer particle masses. We also present results of the convergence of integrated nucleosynthetic yields with increasing tracer particle number. We find that the yields of the most abundant species (mass fraction $> 10^{-5}$) are reasonably well predicted for a tracer number as small as 32 per axis and direction. Convergence for isotopes produced in regions where a constant tracer mass implementation results in poor spatial resolution can be improved by suitably choosing tracers of variable mass.

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1. Introduction

Type Ia supernovae (SN Ia) are believed to be thermonuclear explosions of white dwarf stars. The relative abundances of nuclei synthesized in SN Ia explosions are dependent on the explosion model and play an important role in understanding the chemical evolution of our Galaxy (e.g. [2]). Multi-dimensional numerical simulations of SN Ia explosions have been carried out by several groups for a range of different explosion models (see e.g. [3, 4, 5, 6, 7, 8, 9, 10]). Synthetic light curves and spectra not only depend sensitively on the amount and location of the radioactive nuclei that decay and reheat the ejecta (such as e.g. ^{56}Ni or ^{57}Ni) but also on the amount and location of many other elements such as e.g. Mg, Ca, Ti or Cr, whose (partially ionized) atoms interact with the radiation. For any explosion model, detailed predictions of the isotopic composition of the ejecta are therefore needed. This is commonly done with the tracer particle method (e.g. [11, 12, 13, 9, 14]), for which a large number of tracer particles is placed into the star. The particles are carried along by the flow, recording the local thermodynamic conditions as a function of time. These "trajectories" are then post-processed with a nuclear reaction network and the resulting yields are assigned to the tracer particles final position and velocity, weighted by the mass the particle represents. Historically, tracer particles of equal (constant) mass are used throughout.

2. Variable mass tracer particle method

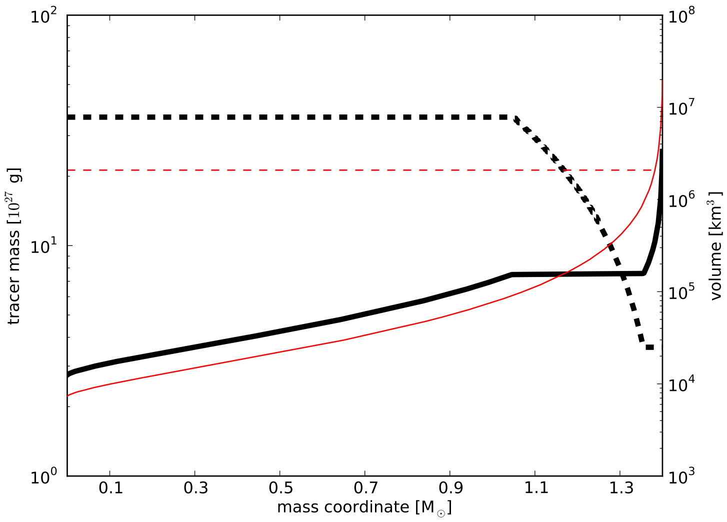

Figure 1: Shown are the mass (dashed lines) and volume (solid lines) represented by a tracer particle as a function of its initial position in the mass coordinate. Thin (red) lines are for constant tracer particle mass. Thick (black) lines are for variable tracer particle mass.

We relax the widely-used constraint of equal mass tracer particles and implement a mass coordinate dependent distribution (more lighter particles at low density, see Fig. 1). These variable mass tracers better resolve the morphology of the low density region where intermediate mass elements

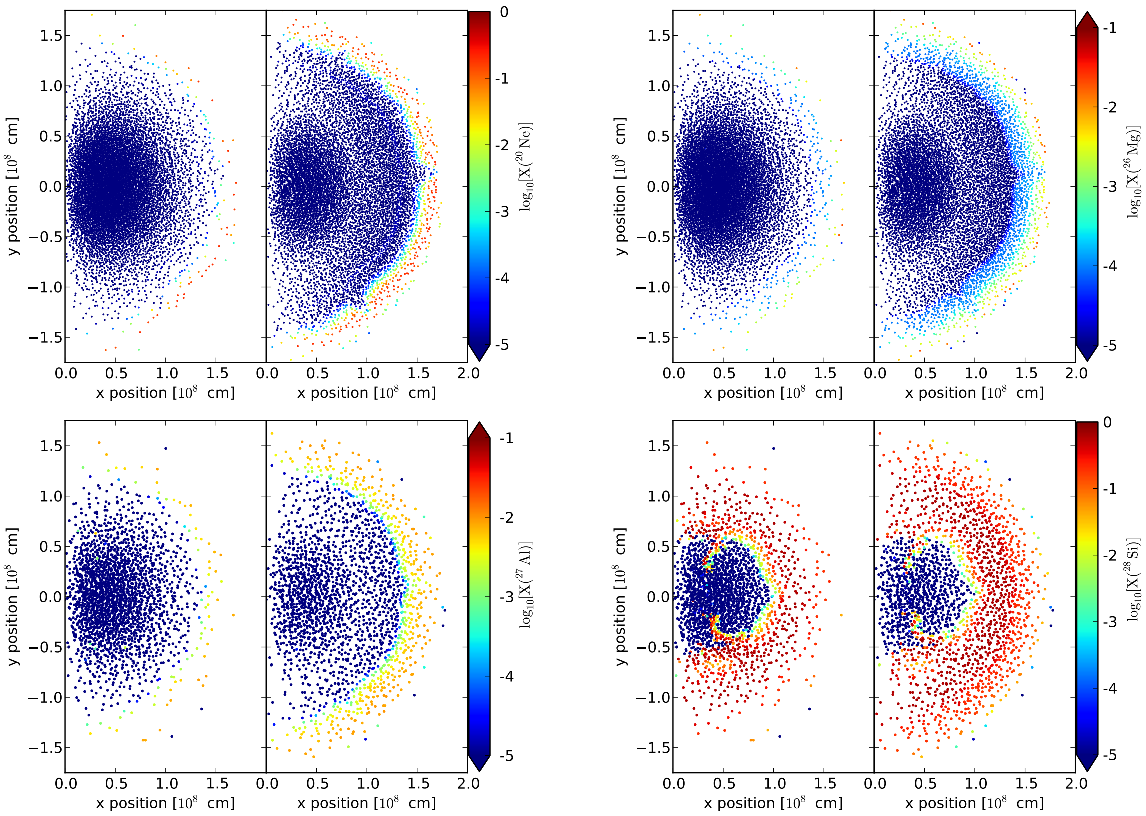

Figure 2: Initial spatial distribution of constant (left side of each panel) and variable (right side of each panel) mass tracer particles colored by the final mass fraction of ^{20}Ne, ^{26}Mg, ^{27}Al and ^{28}Si respectively after freeze-out ($t = 10$ s). The variable tracer mass distributions better resolve the morphology of these isotopes.

form (see Fig. 2). Furthermore, the convergence with particle number of the integrated isotopic nucleosynthetic yields of some intermediate mass isotopes can be improved (see Fig. 3).

3. Conclusion

The tracer particle method yields appear to begin to converge for tracer particle numbers greater than ~32 per axis and direction (see Fig. 3). The yield convergence for nucleosynthetic products of incomplete burning, such as e.g. Mg or Al, can be improved upon by using tracer particles of variable mass. These variable mass tracers can greatly improve the spatial resolution of the lower density nucleosynthetic yield distribution, which could lower the number of particles required to obtain converged light curves and spectra (see e.g. [15]). For further details, please see the journal article associated with this poster [16].

Acknowledgments

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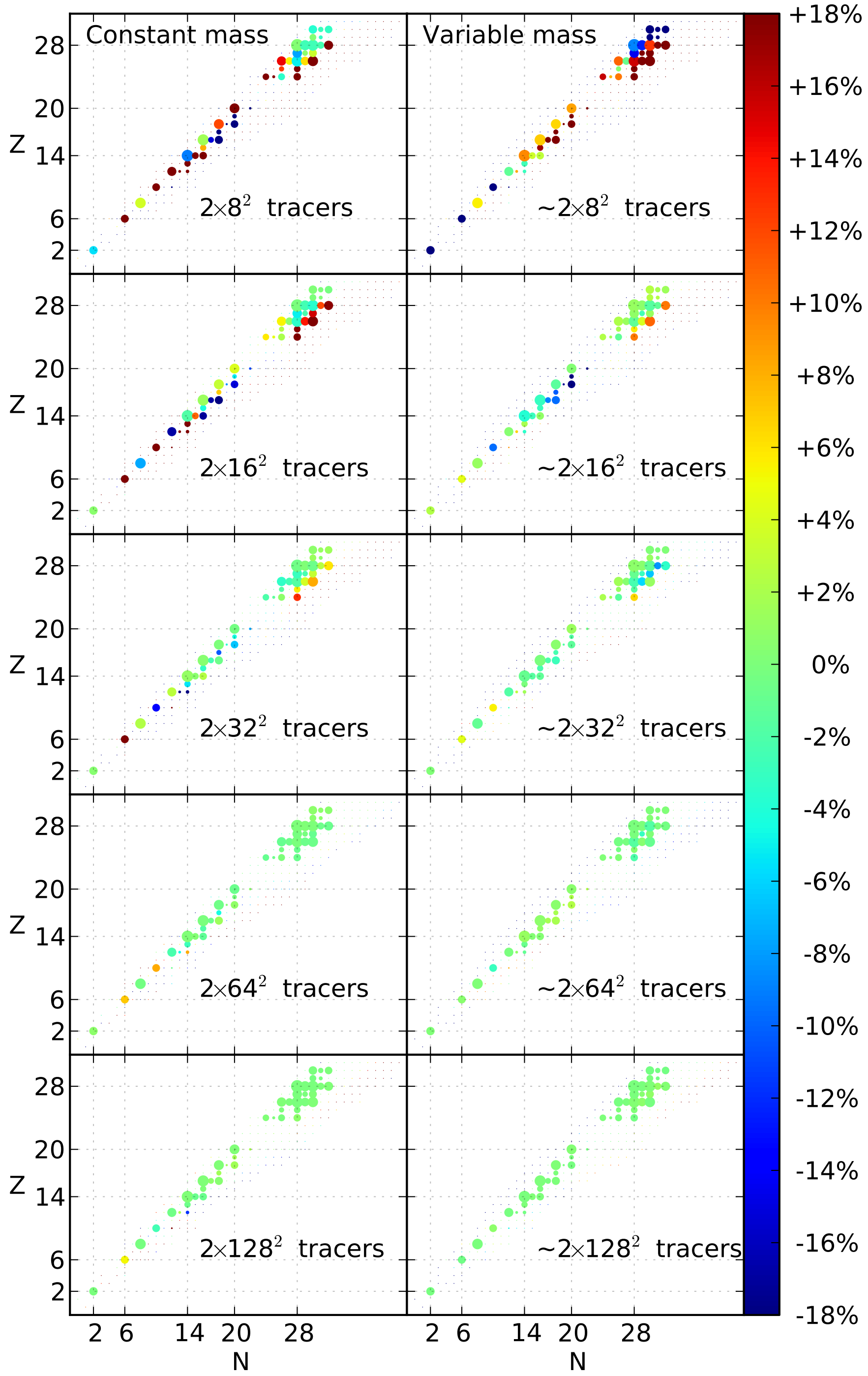

Figure 3: Final ($t = 10$ s) nuclide mass fraction differences $\left[\frac{X_i(2\times N^2)-X_i(2\times 256^2)}{X_i(2\times 256^2)}\right]$ in percent for a sequence of increasing total tracer particle number compared with the highest resolved case containing 2×256^2 tracer particles. The underlying hydrodynamical simulation is the same 2D multi-spot ignition delayed detonation model for all cases. The left column is for tracer particles of constant mass, whereas for the right column the variable tracer mass approach was used. The radius, s_i, of the markers increases with mass fraction X_i according to $s_i = \max\{0.1, 29.9[\log_{10}(X_i)+5]/5+0.1\}$ in arbitrary units. Red means overproduction, blue means underproduction, and green means good agreement with respect to the case with the most tracer particles.

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